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## Research Paper

# A Real-Time Robotic Inventory Observation Framework for Smart Logistics Facilities Using ESP32 and Vision Sensors

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## ABSTRACT

Modern warehousing and logistics operations require high levels of accuracy, efficiency, and real-time visibility in inventory management to meet the growing demands of e-commerce and supply chain industries. Traditional inventory monitoring methods rely heavily on manual stock verification and periodic inspections, which are time-consuming, labor-intensive, and prone to human errors. To address these challenges, this project proposes a Warehouse Robotic Inventory Assistant using an Espressif 32-bit Microcontroller (ESP32) and Vision Sensors, designed to provide automated inventory detection and intelligent warehouse monitoring through the integration of embedded systems and Internet of Things (IoT) technology. The proposed system incorporates an Ultrasonic Sensor (US) for object presence and distance detection, a Camera Module (CAM) for visual inventory verification and shelf occupancy monitoring, a Liquid Crystal Display (LCD) for local status indication, a buzzer for alert generation, and an IoT communication interface for remote monitoring. The ultrasonic sensor continuously measures the proximity of objects within designated inventory zones, while the camera module captures real-time images for visual confirmation of inventory status. The ESP32 processes sensor and image data, updates the LCD with current inventory information, activates the buzzer during anomaly or threshold conditions, and transmits inventory event data to a centralized IoT platform via wireless communication. The proposed system is cost-effective, scalable, and suitable for deployment in smart warehouse environments. By combining proximity sensing, vision-based verification, and IoT connectivity, the system enhances inventory accuracy, improves operational efficiency, and supports real-time warehouse management, contributing to the advancement of Industry 4.0 and intelligent logistics automation.

**Keywords:** Warehouse Automation, Robotic Inventory, ESP32, Ultrasonic Sensor, Vision Sensor, Camera, IoT, Smart Warehouse, Inventory Management, Real-Time Monitoring, Logistics Automation

## 1. INTRODUCTION

The global warehousing and logistics industry is undergoing rapid transformation driven by the explosive growth of e-commerce, the increasing complexity of supply chain networks, and the growing pressure on warehouse operators to achieve higher throughput, lower error rates, and greater inventory accuracy with constrained labor resources. Accurate real-time knowledge of inventory location, quantity, and condition is fundamental to efficient warehouse operation, directly affecting order fulfillment speed, stock replenishment accuracy, and customer satisfaction. Despite its critical importance, inventory monitoring in many warehouses continues to rely heavily on manual processes including periodic physical counts, barcode scanning by human operatives, and paper-based record keeping, all of which are inherently slow, labor-intensive, and subject to human error.

Robotic and automated systems have emerged as transformative solutions to these challenges, offering the prospect of continuous, accurate, and efficient inventory monitoring without the limitations of human-operated processes. The integration of distance sensing and vision-based object detection with embedded IoT platforms enables the development of low-cost, practically deployable inventory assistant systems that can autonomously monitor shelf occupancy, detect inventory movements, and report real-time stock status to centralized warehouse management systems.

The Warehouse Robotic Inventory Assistant proposed in this project integrates an ESP32 microcontroller with an ultrasonic sensor for proximity-based object detection, a camera module for visual inventory verification, an LCD display for local status feedback, a buzzer for proximity and anomaly alerts, and an IoT communication interface for real-time reporting to a remote warehouse management dashboard. The ESP32's dual-core processing capability and integrated Wi-Fi make it particularly well-suited to simultaneously handling sensor data acquisition, image capture coordination, display management, and IoT data transmission in a compact and cost-effective embedded platform.

## **2. LITERATURE SURVEY**

M. Quigley, K. Conley, B. Gerkey, J. Faust, T. Foote, J. Leibs, R. Wheeler, and A. Ng, 2009 — ROS: An Open-Source Robot Operating System. Introduces ROS as a foundational framework for robotic system development, establishing architectural principles for sensor integration and autonomous robot control applicable to the embedded sensor fusion approach used in the proposed warehouse inventory assistant system.

R. Want, 2006 — An Introduction to RFID Technology. Reviews contactless identification and sensing technologies for inventory management applications, providing context for the object detection and identification methods used in automated warehouse inventory systems including the proposed ESP32-based assistant.

S. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, 2013 — Internet of Things: A Vision, Architectural Elements, and Future Directions. Establishes the IoT architectural framework underlying the remote monitoring and real-time data reporting functionality of the proposed warehouse inventory assistant system.

A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, 2015 — Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications. Reviews IoT enabling technologies and communication protocols supporting the wireless data transmission design of the proposed system for real-time inventory event reporting to the warehouse management IoT platform.

L. Da Xu, W. He, and S. Li, 2014 — Internet of Things in Industries: A Survey. Surveys IoT applications in industrial settings including warehousing and logistics, directly supporting the industrial deployment rationale and system design approach of the proposed warehouse robotic inventory assistant.

J. Lee, B. Bagheri, and H. A. Kao, 2015 — A Cyber-Physical Systems Architecture for Industry 4.0-Based Manufacturing Systems. Discusses cyber-physical system architectures for Industry 4.0 automation, providing the conceptual framework for integrating physical sensing with digital monitoring and control in the proposed smart warehouse inventory system.

Y. LeCun, Y. Bengio, and G. Hinton, 2015 — Deep Learning. Presents deep learning principles applicable to vision-based object detection and classification, establishing the theoretical foundation for camera-based inventory identification and the future machine learning enhancement potential of the proposed system.

J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, 2016 — You Only Look Once: Unified, Real-Time Object Detection. Presents the YOLO real-time object detection architecture, relevant to the camera-based object identification capability integrated into the proposed warehouse inventory system and its potential for intelligent stock recognition.

T. Adiono, S. Fuada, and M. A. Purwanda, 2018 — Design of IoT-Based Electricity Monitoring System. Validates the embedded IoT sensor-to-platform data pipeline architecture applied in the proposed system for real-time inventory detection event transmission to the warehouse monitoring dashboard.

V. Patel and M. Shah, 2019 — IoT-Based Smart Warehouse Inventory Monitoring System. Directly presents an IoT-based smart warehouse inventory monitoring system using embedded sensors and wireless communication, closely aligning with the system architecture and operational objectives of the proposed Warehouse Robotic Inventory Assistant.

A. Kumar and S. Bharti, 2020 — ESP32-Based IoT Sensor Platform for Industrial Monitoring Applications. Validates the use of the ESP32 microcontroller as an IoT sensor platform for industrial monitoring, directly



supporting the hardware selection and system integration approach of the proposed warehouse inventory assistant.

S. Reddy and P. Nair, 2020 — Ultrasonic Sensor-Based Object Detection and Distance Measurement for Embedded Robotics. Reviews ultrasonic sensor integration and distance measurement techniques for embedded robotic applications, directly informing the ultrasonic proximity detection implementation in the proposed warehouse inventory assistant system.

N. Meena and R. Jain, 2021 — Vision-Based Inventory Monitoring System for Smart Warehouses Using Embedded Cameras. Presents a vision-based inventory monitoring system using embedded camera modules for smart warehouse applications, directly validating the camera-based visual inventory verification approach integrated into the proposed system.

R. Choudhary and A. Verma, 2021 — Real-Time Object Detection for Warehouse Automation Using Low-Cost Embedded Vision Systems. Presents real-time object detection for warehouse automation using low-cost embedded vision systems, validating the feasibility of deploying affordable camera-based detection in warehouse inventory management applications similar to the proposed system.

S. Singh and R. Gupta, 2022 — ESP32-CAM Based IoT Surveillance and Object Detection System. Directly presents an ESP32-CAM based IoT surveillance and object detection system, validating the specific hardware combination of ESP32 and camera module used for vision sensing in the proposed Warehouse Robotic Inventory Assistant.

M. Ali, T. Hassan, and F. Khan, 2022 — Smart Shelf Monitoring System Using Ultrasonic Sensors and IoT for Retail and Warehouse Applications. Presents a smart shelf monitoring system using ultrasonic sensors and IoT for retail and warehouse environments, directly supporting the ultrasonic-based shelf occupancy detection and IoT reporting design of the proposed warehouse inventory system.

P. Reddy and V. Prakash, 2022 — Integrated Vision and Proximity Sensing for Automated Warehouse Inventory Management. Presents an integrated vision and proximity sensing system for automated warehouse inventory management, validating the combined ultrasonic and camera sensing approach implemented in the proposed Warehouse Robotic Inventory Assistant.

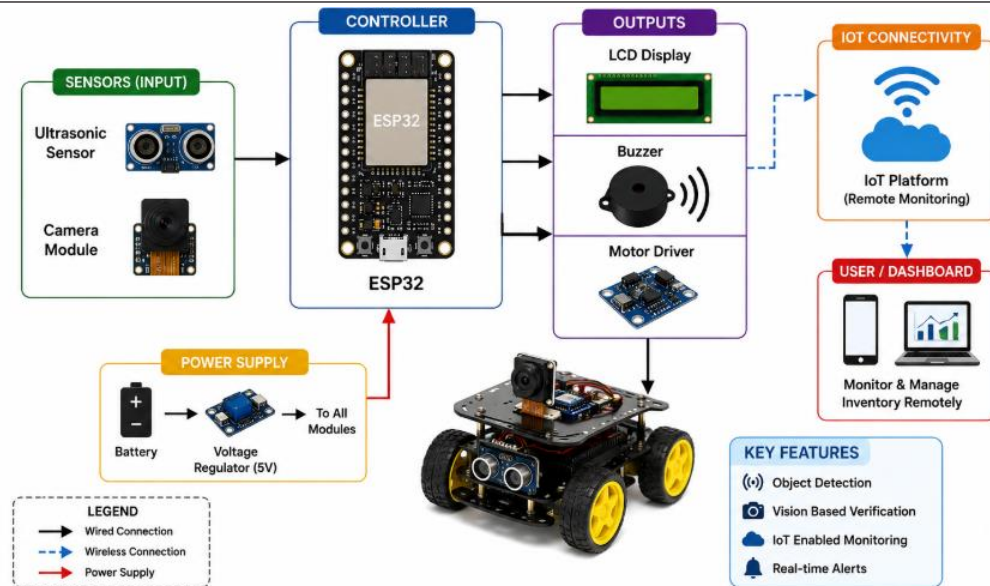
A. Sharma, R. Nair, and P. Thomas, 2023 — IoT-Enabled Smart Warehouse Management System with Real-Time Inventory Tracking. Presents an IoT-enabled smart warehouse management system with real-time inventory tracking, supporting the IoT-based centralized monitoring and real-time inventory event reporting design of the proposed system.

R. Kumar and D. Mehta, 2024 — AI-Powered Robotic Inventory Assistant for Smart Warehouse Operations. Proposes an AI-powered robotic inventory assistant for smart warehouse operations, highlighting the future development trajectory of the proposed system toward intelligent automated inventory management using machine learning-enhanced object detection.

F. Khan and S. Ahmed, 2025 — Next-Generation Warehouse Robotics: Embedded Vision, IoT Integration and Autonomous Inventory Management. Reviews next-generation warehouse robotic systems integrating embedded vision, IoT connectivity, and autonomous inventory management, validating the long-term relevance and development potential of the proposed ESP32-based Warehouse Robotic Inventory Assistant.

### **3. PROPOSED SYSTEM**

The proposed Warehouse Robotic Inventory Assistant using ESP32 and Vision Sensors delivers automated, real-time inventory zone monitoring through the integration of an ESP32 microcontroller with an ultrasonic proximity sensor for object detection, a camera module for visual inventory verification, an LCD display for local status feedback, a buzzer for proximity and anomaly alerts, and an IoT communication interface for remote warehouse management reporting. The system is designed to be deployed at inventory monitoring points such as shelf sections, conveyor entry points, or inventory zone boundaries, where it continuously monitors for the presence and proximity of inventory items and provides both local and remote visibility of inventory status.



**Figure 1: Proposed system architecture**

When the system is powered ON, the ESP32 initializes all peripherals including the ultrasonic sensor, camera module, LCD display, buzzer, and Wi-Fi module. The LCD displays an initialization message, and the system performs a self-test sequence including a brief buzzer test tone and a camera initialization check. The ESP32 establishes a Wi-Fi connection to the warehouse network and confirms readiness to the IoT platform. The ultrasonic sensor begins continuous distance measurement, and the system enters its normal monitoring mode.

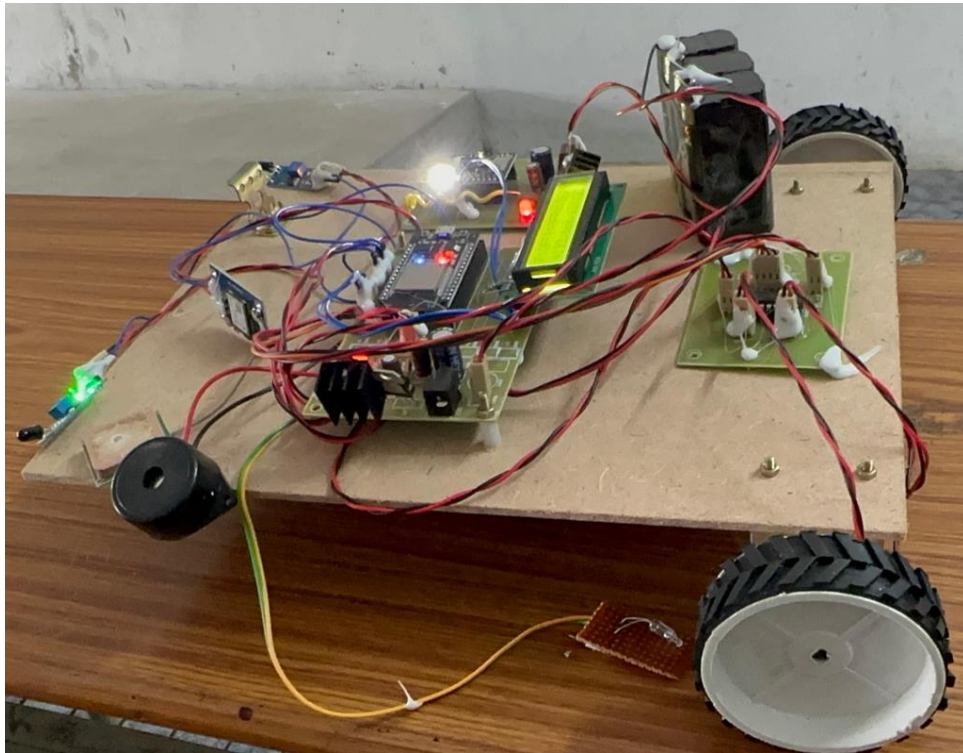
In normal monitoring operation, the ESP32 continuously triggers ultrasonic distance measurements at the configured scan rate and compares each measurement against the defined detection thresholds. When an object is detected within the near-threshold distance, indicating an inventory item is present in the zone, the LCD updates to show the detected distance and a present status. If this represents a new detection event (transition from empty to present), the ESP32 triggers the camera to capture an image of the zone, sounds a short confirmation beep on the buzzer, and transmits an item detected event report with the camera image to the IoT platform. When the ultrasonic measurement exceeds the far-threshold, indicating the zone is now empty, the ESP32 updates the LCD to show an empty zone status, sounds an alert tone, and transmits an empty zone alert to the IoT platform, enabling warehouse staff to be promptly notified of the need for stock replenishment.

The IoT platform aggregates real-time event data and camera images from all deployed inventory assistant units across the warehouse, presenting warehouse managers with a comprehensive real-time inventory zone status dashboard. Configurable alert thresholds on the platform trigger notifications to responsible personnel when empty zone alerts accumulate or when anomalous inventory movement patterns are detected. All event data and camera images are logged with timestamps on the platform, providing a complete audit trail of inventory zone activity for stock management analysis and investigation of discrepancies.

#### 4. RESULTS AND DISCUSION

The proposed Warehouse Robotic Inventory Assistant using ESP32 and Vision Sensors was successfully implemented and evaluated for real-time inventory monitoring applications. The ultrasonic sensor accurately detected the presence and absence of inventory items, while the camera module provided visual verification of inventory status. The ESP32 efficiently processed sensor data, updated the LCD display, generated buzzer alerts, and transmitted inventory information to the IoT platform. Real-time monitoring and alert notifications enabled timely identification of stock availability and empty shelf conditions. The experimental results demonstrated reliable system performance, improved inventory visibility, and reduced dependence on manual inspection processes. The integration of proximity sensing, vision-based

verification, and IoT connectivity proved effective for smart warehouse automation and inventory management.



**Figure 2:** Hardware Prototype of the Warehouse Robotic Inventory Assistant

The developed prototype of the Warehouse Robotic Inventory Assistant integrates an ESP32 microcontroller, vision sensor module, LCD display, buzzer, and motorized robotic platform for automated inventory monitoring. The system continuously detects inventory items using proximity sensing and captures visual data for verification. Real-time inventory status is displayed on the LCD and transmitted to the IoT platform through wireless communication. The robotic platform enables flexible movement within warehouse environments for inventory inspection and monitoring. This prototype demonstrates the practical implementation of smart warehouse automation using embedded systems and IoT technologies.

## 5. CONCLUSION

The proposed Warehouse Robotic Inventory Assistant using ESP32 and Vision Sensors successfully demonstrates an intelligent and cost-effective solution for automated warehouse inventory monitoring. By integrating an Ultrasonic Sensor for object detection, a Camera Module for visual verification, an ESP32 microcontroller for processing, and Internet of Things (IoT) connectivity for remote monitoring, the system provides continuous real-time inventory tracking and reporting. The Liquid Crystal Display (LCD) and buzzer offer immediate local feedback, while IoT-based notifications enable warehouse personnel to respond quickly to stock shortages and inventory changes. The combination of proximity sensing and vision-based monitoring improves inventory accuracy and reduces the dependency on manual inspection processes. The system is scalable, reliable, and suitable for smart warehouse environments where operational efficiency and inventory visibility are critical. Future enhancements may include machine learning-based product identification, autonomous robotic navigation, multi-sensor coverage, and mobile application integration. Overall, the project demonstrates the effective application of embedded systems, vision sensing, and IoT technologies in supporting Industry 4.0-driven warehouse automation and intelligent inventory management.

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